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AGARD ADVISORY REPORT No.249

Technical Evaluation Report on the Guidance and Control/Flight Mechanics Panels Joint Symposium on The Man-Machine Interface in Tactical Aircraft Design and Combat Automation

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Advisory Report No.249

TECHNICAL EVALUATION REPORT

on the

GUIDANCE AND CONTROL/FLIGHT MECHANICS PANELS JOINT SYMPOSIUM

on

THE MAN-MACHINE INTERFACE IN TACTICAL AIRCRAFT DESIGN AND COMBAT AUTOMATION

by

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Technical Evaluation Report of the Joint GCP/FMP Symposium, held in Stuttgart, Germany from 28 September to 1 October 1987.

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- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
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PREFACE

The meeting announcement contained statements substantiating the need for and the objectives of this Joint FMP and GCP Symposium with AMP contribution:

> Technological advances have made possible the development of system capabilities which allow more effective weapon system operation under conditions, such as low altitude, high speed, night and all weather. Further challenges from the threat environment in the 1990s are predicted. Emerging technologies allow greater automation and integration of systems/functions. Therewith the criticality of the pilot/vehicle interface and interaction functions design increases considerably.

The symposium sought to address these critical issues of combat automation and the man-machine interface.

The Symposium was held in Stuttgart, Federal Republic of Germany, 28 September to 1 October 1987.

* * *

Le texte de l'annonce de réunion souligna l'opportunité et les objectifs de ce Symposium conjoint FMP/GCP organisé avec la participation de AMP:

> Les progrès technologiques ont rendu possible le développement de systèmes capables de rendre plus efficace la mise en oeuvre d'un système d'armes dans des conditions difficiles telles que basse altitude, grande vitesse, utilisation de nuit et tous temps. Davantage de défis seront à affronter dans l'environnement complexe de la menace prévue dans les années 1990. L'émergence de plusieurs technologies permet une plus grande intégration et une automatisation plus poussée des systèmes/fonctions. L'interface pilote/véhicule et la conception des fonctions interactives deviennent, par conséquent, d'autant plus critiques.

Ce symposium s'est efforcé d'abord ces problèmes critiques de la relation combat automatisé/homme-machine.

Le symposium s'est tenu à Stuttgart, République Fédérale d'Allemagne, du 28 septembre au 1 octobre 1987.

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CONTENTS

ABBREVIATIONS

AFTI	Advanced Fighter Technology Integration
AI	Artificial Intelligence
BVR	Beyond Visual Range
DVI	Direct Voice Input
HMD	Helmet Mounted Display
HOTAS	Hands On Throttle And Stick
HUD	Head-Up Display
ICAAS	Integrated Control And Avionics for Air Superiority
IR	Infrared
MMI	Man-Machine Interface
NBC	Nuclear-Biological-Chemical
PCCADS	Panoramic Cockpit Control And Display System
R&D	Research and Development
TRN	Terrain Referenced Navigation
WVR	Within Visual Range

1. Introduction

During the last seven years a number of activities took place within the NATO community which all served the same purpose:

To extend and improve our knowledge and rules data base serving the task of man-machine interface engineering in design and development of high performance air combat systems.

The knowledge gap was first formulated during the U. S. National Academy of Science study on "Automation in Combat Aircraft", held in 1981. It gave the impetus for the study of the GCP/WG.07 on "Improved Guidance and Control Automation at the Man-Machine Interface" from 1983 to 1985. The resulting advisory Report Ar-No. 228 was published in December 1986.

In April 1984 the NATO Defense Research Group, Panel VIII held a Workshop on "Application of System Development" in Shrivenham, England. The workshop concentrated on advanced crew station design, cockpit automation technology, and operator performance.

The 40th GCP Symposium on "Guidance-Control-Navigation Automation for Night All-Weather Tactical Operations, held in Den Haag 21-24 May 1985 was another occasion where the advances in automation and Man-Machine-Interface (MMI) design were reviewed.

During the same time a number of national research projects were initiated in the various NATO Nations dealing with the above formulated objective. These projects included analyses, flight test programmes, and experimental aircraft developments to demonstrate automation technologies and capabilities including the advances in crew station integration.

This joint GCP/FMP Symposium summarizes the results achieved until to-day from most of these projects.

2. Programme Summary

The programme of this Symposium was organized into six technical sessions:

I COMBAT SCENARIOS AND MISSION SEGMENT REQUIREMENTS

II HUMAN CAPABILITIES AND LIMITATIONS

III TECHNOLOGICAL CAPABILITIES AND LIMITATIONS CONCERNING AWARENESS

IV TECHNOLOGICAL CAPABILITIES AND LIMITATIONS OF COMBAT AUTOMATION

VI SYSTEM INTEGRATION

It included 31 presentations, followed by a final discussion.

Session I including the key note paper represented an overview of the operational task requirements in the BVR and WVR combat scenario, and the resulting challenge for Man-Machine-Interface (MMI) design in the "electronic cockpit". The experiences with to-days fighter cockpits were stated, and the influencing factors as new sensor features, refined mission planning introducing the use of Expert Systems, and new interface devices were highlighted.

Session II comprised the contributions of the AMP representatives. Herein the design challenges were reviewed for interfacing man with his system as well as providing the appropriate environmental protection against heat loads, high-g, and high-g onsets. Particular concern was given to modeling man's performance, to workload measurement and the respective metrics.

Session III focused on the technological capabilities of enhancing situation awareness and system handling by means of sensor fusion, improved display and control devices, and by including a comprehensive set of operational requirements data in the MMI design and development process, based on pilot/operator experience.

Session IV concentrated on the various facets of combat automation realisation: The new role of the pilot as manager and supervisor, his concern with the reliabiltiy of automation features; the demonstration of the integrated cockpit with progressive MMI desing including new control and display systems; the perspective of expert systems application; and with the pilot's experience with, and view of cockpit automation.

Session V dealt with the implementation of the advanced crew station and pilot integration, and with the development of new flight control systems and evaluation of the short center-, the side-stick and the application of active and passive control.

Session VI represented an overview on the recent achievements as well as the future perspective in systems integration demonstrated in terrain referenced avionics with sensor fusion, in advanced helicopter cockpit and control configuration simulation, in the integrated control and avionics for air superiority (ICAAS) project, and in the AFTI/F-16 flight test program.

3. Technical Evaluation

The technical evaluation is comprising the author's conclusions from observations and discussions during the symposium together with opinious and suggestions stated in the participants questionnaires.

A detailed evaluation of the questionnaires was sent to the GCP, FMP and AMP.

3.1 Session I - Combat Scenarios and Mission Segment Requirements

Mr. Ramage, the GCP Symposium Co-Chairman and Chairman of Session I opened the technical programme. He pointed out that the emphasis of the symposium was put on the subject of automation and the man-machine interface. The evolving combat scenarios and the resulting operational requirements give a strong impetus for advances in automation. And the progressing automation requires new MMI concepts enabling the pilots/aircrews to deploy all operational functions and capabilities designed into the manned combat system.

It was further stated that pilot acceptance, system effectiveness and safety are of paramount importance in introducing increasing levels of combat automation.

The keynote paper by Air-Vice Marshall Walker related to the new scenarios allowing air combat BVR up to 100 miles, compared to 38 miles to-day, 17 miles during the Korean war, 10 miles in the II nd and 4 miles in Ist World War. The 'look' and 'reach' capabilities of our complex systems potentiate the 'situation a wareness' needs, particularly in a multi threat combat envorinemnt.

A study revealed that in 80 % of aircraft shot down the pilots had not even seen their attacker.

The pilots should be "enabled by design" to concentrate on their operational tasks instead of on flying the aircraft and monitoring the subsystems. The more does this apply to the single crew fighter, which is envisaged for reason of cost and recruitment limitations.

Importance was seen in design for reliability, maintainability, and environmental protection against g-load/g-onset and EMP in the normal range.

The first three papers (including the keynote) reviewed the need for a cockpit design for operation, favouring HOTAS (the F-18, not the F-16 concept) against DVI, and the helmet mounted display to enlarge the visual field in head-up operation, and the "software intensive" cockpit with an easy and transparent moding concept.

The need for use of artificial intelligence (AI) and expert systems for mission and attack profile planning is emerging, because of the increasing number of factors (threats, sensors, weapons, modes) to be taken into account. This was discussed in paper three and four.

3.2 Session II - Human Capabilities and Limitations

Papers 5. to 10. and 29. represented the AMP contributions. In paper 5. the stresses were reviewed that limit human performance, which are mainly g-load/g-onset, thermal stress, vibration, noise and NBC defence. These stresses were discussed in the light of the operational demands, the requirements for protection by design and the "pilot agility" limitations remaining or resulting therefrom. With appropriate seat and *g-protection equipment design the pilot is not the limiting factor in high performance* aircraft. The tolerances and the means and methods to improve them were shown in paper 6. based on centrifuge and flight test results.

In paper 7. a model to predict visual performance dependent from man-display and -cockpit conditions was presented. This represents a true need for the designer. Display and cockpit visibilty specifications all lack the availability of data predicting visual performance under given physical conditions of color, contrast enhancement filter, resolution and other factors. Such a model helps to achieve objective display specifications.

Papers 8. to 10. dealt with the assessment of pilot workload in simulator and flight test environment. Workload metrics is still an issue of concern for further research and development.

The first half of this session dealt with life support, aircrew equipment, and man-display interface requirements. This represents the system-oriented view of human capabilities and limitations. Workload and its measurement represents the man-centered view. A considerable portion of the technically oriented GCP and FMP auditory expected more data on human functional capabilities and limitations, which could be readily transformed into requirements for system and equipment specifications. If this were easily achievable, man would not be a human being, with all his adaptability, variability, and non-linearities in performance. Paper 29. of session VI, which did not really come across to the auditory, related to a four-volume "Engineering Data compendium", which is layed out to providing human factors data tailored for direct use by designers. This seems worth mentioning.

3.3 Session III - Technological Capabilities and Limitations Concerning Situation Awareness

This session contained five papers dealing with different facettes of methods and means to provide better situation awareness and assistence to the pilot.

In session I the operators showed strong concern towards operator involvement and cooperation with the designers. Paper 11. referred to a method by which the operational requirements, comprising mission analysis, information element, control functions and cockpit moding requirements are established in direct collaboration between designers and operators.

Paper 12. illustrated a technical solution facilitating the manual activities for cockpit moding and mission data entry.

A simulator study with a "Panoramic Cockpit Control and Display System" (PCCADS) to improve situation awareness was presented in paper 13. This system replaces the individual headdown displays, renders better utilization of panel space, allows integrated display of the relevant information, and provides in combination with the HUD and HMD great angular visual field. The flexibility of pilot operation is enhenced by the touch sensitive display characteristic. This display concept was already discussed in the GCP report on "Improved Guidance and Control Atomation at the Man-Machine Interface" (AR 228). *An exellent concept, projected into a not very near future.*

Another display device offering powerful new capabilities is the "Computer Generated Map Display", described in paper 14. The system offers perspective views of terrain, improved radar predictions, threat areas display and improved navigation and updating. The integration of stored and actual flight and sensor data is a promising means to improve situation awareness.

Multisensor Target Reconnaissance using a knowledge based sensor fusion system combining radar (as primary sensor) with IR information was presented in paper 16. The development of means, procedures and display techniques for sensor fusion is one of the areas which require great concern as far as automation and application of AI for pilot support is concerned.

3.4 Session IV - Technological Capabilities & Limitations of Combat Automation

The new role of the pilot in the future fighter aircraft is still not well enough defined (Paper 17.). Supervision of systems is still required besides the supervision of the mission. Automation should take into account the pilot's mental representation of his tasks. And this representation changes with experience, with increasing confidence in system functions reliability, and is dependent on the system reconfiguration capabilities in failure conditions. To assist the pilot in the "electronic cockpit" the use of AI as MMI is under research (Paper 19., second part). An expert system for reasoning and decision making support in tactical, attack planning and systems health monitoring is under development.

The state of the art concerning future fighter cockpit development needs (Paper 21.), and realisation in demonstrator aircrafts as the RAFALE (Paper 19, first part) and EAP (Paper 23.) have well been illustrated. Each of the solutions has its benefits. The combination of the HUD with a collimated HDD in the RAFALE is very promising as well as the display of the "energy status" in conjunction with the velocity vector in e. g. the approach format on the HUD.

In the EAP the display/control moding including HOTAS, and a sophisticated warning concept shows what can be achieved to-day. The needs were already stated in the study on "Automation in Combat Aircraft" in 1981. Meanwhile they have been formulated in more detail, and the technological capabilities have been demonstrated. However there are still limitations in the display technology (full color, high resolution, high update rate, sunlight readability), in pilot support to prevent that high workload situations develop (Paper 21.), in the state of the art of AI expert system to attain a synergistic combination of human and machine capabilities.

The state of R & D in the development of HMD systems was reviewed in Paper 22. The "virtual panoramic display" helmet system is at present developed and is expected to be flight tested by 1991. The concept of display of information and use of the HMD needs further definition.

3.5 Session V - Crew Station Implementation

The state of the art of the Advanced cockpit was described in Session IV (Papers 19., 20., 23.) Paper 24. deals with pilot integration and the implications on the design of advanced cockpits. The interesting view of the "enclosed cockpit" is presented based on the assumption of restrictions in the visual field of view resulting from NBC protection and in mobility due to high-g, low level operation. These assumptions however, apply only if the development of the aircrew protective equipment is not improved and subjected to advanced development alongside with the advances in other cockpit and MMI systems. Paper 23., deals further with MMI means and methods by which the challenge of pilot integration into the future cockpit can be met. Further R & D is required.

Papers 25. to 28. deal with new concepts and developments concerning the flight control MMI. Side- and center-stick parameters and transfer gain shapings are compared by simulation (Paper 25.). The active and passive side stick controller concept is compared in a tracking task simulation in Paper 26. Considerable improvement in tracking performance was found for the "active" against the "passive" control stick. The "active control stick" concept implies re-installing the connection between the pilot and the aircraft's control surfaces, which was lost with the advent of fly by wire flight controlsystems. In papers 27. and 28. (see also 33.) the recent R & D and flight test status on the new helicopter control concepts was reviewed. The replacement of the conventional controllers by new integrated control elements is a means to reduce workload and fatigue in helicopter flying.

3.6 Session VI - System Integration

This session comprised in the papers 30. to 33. recent achievements and results of advanced projects, which are the investigation of "low level night operation" applying EO-sensors in combination with terrain reference data base systems, the "integrated control and avionics for air superiority" programme, the AFTI/F-16 programme, and a study on "advanced helicopter cockpit and control configurations". Paper 30. concludes - the only paper that contained classified information - that current thinking on future system integration should include the combined application of FLIR and CO_2 laser with TRN as flying aid for low level operation. Functional integration of sensors, fire control and flight control (paper 31) even up to a "fully automated attack system" (paper 32.) combined with investigation of the advanced technologies of the system-pilot interface are the paramount objectives of the ICAAS and the AFTI/F-16 programmes.

The use of the emerging technologies for helicopter operations in adverse weather, forced low-level and air-to-air engagements in a two man compared to a one man cockpit was the objective of paper 33. All four papers illustrate the immense effort required to achieve the system integration and automation level required to allow single crew, all night all weather, low level operation of future combat systems including helicopter systems, and to achieve BVR engagement capability with fast transition to close-in-combat in air-to-air missions.

3.7 Final Discussion

In the Final Discussion the session chairmen summarized their views and conclusion. The subsequent discussion suffered from the (usual) time limitations.

Most of the aspects presented and discussed are included either in the evaluation chapter or in the questionnaire contributions. A few supplementary statements are made here to highlight certain contributions:

- New technologies have their full benefit in terms of system effectiveness only when they are applied embedded in the operational context and given situation awareness.
- There is still a conflict concerning cost effectiveness of "tailored-to-task" against "multi-role" air combat systems.
- Reliability is not a matter of mathematics only. One single failure can destroy the built up confidence into a system or technology.
- we must keep in mind that AI is not comparable with human intelligence. Memory and experience are only tools.
- The pilot does not want to put his life into the hands of automatic systems. They shall only aid, support and protect him.
- Unload man from system and flight management tasks, and make him free for the mission.

4. Conclusions and Recommendations

4.1 Conclusions

The Symposium was successful and the state of the art of MMI was well covered by the distribution of the papers over the following issues:

	No. of papers
o Operators evaluation of mission and MMI requirements related to systems	5
o Man's role and information/control requirements for mission and mission segments	4
o Human limitations, modelling and workload measurement	6
o New technologies, sensor fusion, application of AI	6
o Flight control devices, control configurations	4
o Systems integration, automation achievements, programmes	6

The joint Panel approach met certain reservations in the auditory. In spite of that it is felt that this multi-disciplinary approach is required now and then to force designers, operators and human factors specialists to "look over their fence", and to be confronted with the MMI aspects as viewed from "the other side".

The major conclusions of this technical evaluation including the questionnaire are:

(1) The preparation of human factors data for ready application of knowledge and rules by the designer remains a problem.

(2) The MMI is more than displays, controls and the software of systems functions. Interfacing man with his cockpit includes the seat, the personal equipment, and constraints resulting therefrom and from operation in high-g or in low level stress environment.

(3) The demonstrator aircraft programmes (RAFALE, EAP) and the systems integration and flight test programmes (AFTI/F-16, ICAAS) illustrate the present state of the art of the "electronic cockpit" and the achievements in integration and automation.

(4) The status reviewed in the report on "Guidance and Control Automation at the Man-Machine Interface" (AR 228), prepared by the GCP Working Group No. 7, is still "state of the art". It has not become out of date because of recent developments.

(5) There is no break-through in display technology (e. g. CRT,LCD) high resolution, color, high frame rate for operation under high ambient light level.

(6) Sensor fusion realisation is beginning to emerge. However, the tools (knowledge and rule based algorithms) are not developed as yet for application to system specifications for the next generation fighter aircraft.

(7) There are display concepts available leading into the future:

- o The PCCADS or "glass cockpit".
- o The HMD using the visor as display surface on a light weight helmet.
- o The computer based horizontal situation display for navigation, and mission management.

(8) The impact of digital data bases coupled with AI systems is fundamentally profound. Expert System concepts are being developed for planning and diagnostic tasks, such as mission planning or systems health monitoring.

The availability of AI tools applicable to decision aiding in the cockpit in real time operations, such as target identification, prioritization, and acquisition will take several years to fully mature.

Additional conclusions may be taken from the final discussion, para. 3.7 and parts of the questionnaire evaluation, available at the GCP, FMP and AMP.

4.2 Recommendations

A great number of recommendations have been made by those participants who answered the questionnaire. These recommendations as well as those from the TER are summarized as follows:

(1) As said in the conclusions:
a joint Panel symposium covering MMI matters from all aspects is proposed to be held about every fifth year. This is considered appropriate to review new technical and technology developments.

The MMI Panel as proposed in one attendees questionnaire is not supported here, on the basis that adequate representation is already provided through the GCP, FMP, AVP and AMP.

The recommendations made in the following concern R & D issues, which could be promoted by AGARD giving the respective expertise:

(2) The conclusions made concerning display technology (4.1-3) and the display concepts (4.1-7) should lead to respective R & D activities, to better understand the integration issue.

Example:
As far as the HMD is concerned, its compatibility with the HUD, and its limitations dependent on cockpit structure and pilot's head movement should be included in the studies.

(3) The "active control stick" concept is recommended to receive greater concern (see para 3.5).

(4) Sensor fusion investigations were presented which are very promising. However a systematic concept needs to be developed taking into account typical sensor combinations applicable to specific tasks, e. g. threat assessment, target prioritization, low level navigation.

This is considered to be a neccessary prerequisite to achieve advances in concept formation and definition of AI requirements for pilot decision aiding in the combat environment.

(5) Development of real time decision aiding concepts should be accelerated to provide the necessary total combat situation awareness.

In summary several emerging technologies are beginning to spawn major innovations in tactical aircraft design. Combat automation, pilot decision aiding, sensor fusion and "super-Cockpit" notions, to name only a few, offer the opportunity for substantial mission effectiveness improvements.

Along with the introduction of new technologies comes the challenge of properly integrating these technologies, so that the pilot or human operator can employ the total weapon system effectively under realistic combat conditions.

APPENDIX

Final Programme

The Man/Machine Interface in Tactical Aircraft Design and Combat Automation.

OPENING CEREMONY

OPENING ADDRESS by GenMaj Schild,
Commander Wehrbereich V

OPENING SESSION
Chairmen: FMP - Dr. A. Filisetti
GCP - Mr. K. A. Peebles

KEYNOTE ADDRESS

1. Man-Machine Interface - Operator's Viewpoint
Air Vice-Marshal J. R. WALKER (UK) — AAFCE, Ramstein, GE

SESSION I - COMBAT SCENARIOS AND MISSION SEGMENT REQUIREMENTS
Chairmen: H. WUNNENBERG, GE & J. RAMAGE, US

2. The CF-18 Cockpit - An Operational Fighter Pilot's Perspective — CFB, Baden-Baden, GE
Major P. DEACON, CAF

3. Mission Scenarios, Planning and Requirements
G. W. MATTHES — AFFTC, Edwards AFB, CA, US

4. Expert System for Low Level Tactical Mission Preparation
P. BOURRET, G. VERFAILLIE — CERT, Toulouse, Fr
M. CERF, J. GALLET, M. ROBERT — MATRA, FR

SESSION II - HUMAN CAPABILITIES AND LIMITATIONS
Chairmen: R. AMALBERTI, FR (for AMP) & R. JONES, UK

5. Human Limitations in Flight and Some Possible Remedies
D. C. READER — MOD, London, UK

6. The Pilot is not the Limiting Factor in High Performance Aircraft
R. R. BURTON, W. C. ALEXANDER — USAF, Brooks AFB, Texas, US

7. A Model to Predict Visual Performance at the Man-Display Interface in the Cockpit
D. F. JOHNSON — BAe, Filton, Bristol, UK

8. Pilot Workload Assessment - A Flight Test Approach
R. M. PAPA, J. R. STOLIKER — AFFTC, Edwards, AFB

9. Consideration Concerning the Assessment of Pilot Workload for complex Task Conditions
R. C. van de GRAAF — NLR, Amsterdam, NE

10. Advances in Workload Measurement for Cockpit Design Evaluation
M. VIKMANIS — AAMRL, Wright-Patterson, AFB, Ohio, US

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14. Abstract

A Keynote address and thirty one papers were presented at the Joint GCP/FMP Symposium, held in Stuttgart, Germany ~~from 28 September to 1 October 1987~~ under the following headings: Combat scenarios and mission segment requirements; Human capabilities and limitations; Technological capabilities and limitations concerning situations awareness; Technological capabilities and limitations of combat automation; Crew station implementation; System integration. The Keynote Address and twenty five papers are published in CP-425 (one paper was not available at the time of printing) and the four remaining classified papers are included in CP-425 (Supplement). Kr...

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